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Microwave Plasma CVD of Silicon Nanocrystalline and Amorphous Silicon as a Function of Deposition Conditions

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Abstract

Using ECR-CVD (electron cyclotron resonance-chemical vapor deposition) , we can make amorphous-silicon (a-Si) and nanocrystalline (nc-Si) thin films. We are looking forward to improve the photo/dark conductivity ratio (σ_p / σ_d) by measuring the photo and dark current-voltage (I-V). In the ECR deposition, there are several factors which we can control and adjust for improved results, such as the amounts of silane and argon, the vacuum, and the temperature of the substrate. These become the critical factors for ECR deposition in order to make better films. Input gases consist of Ar, 2%SiH_4 in He and H_2. In the process, SiH_4 is decomposed into SiH_x. A residual gas analyzer (RGA) gives composition in the plasma. Because Ar possibly etches the substrate and Si is to be deposited, the best RGA signal is obtained with low Ar content. This work serves to correlate process conditions, RGA signals and electrical data. The best RGA signal occurs for 5 mTorr Ar, 60 mTorr SiH_4:He, and power of 600 W. Best value of dark conductivity (σ_d) was 1.53×10^{-9} S/cm and1.58×10^{-5} S/cm for photo conductivity (σ_p). High value of σ_p and low value of σ_d indicate material with fewer defects. Adding extra H_2 improves the photo-conductivity (σ_p). Applications of these films are heterojunction solar cells and thin film transistors. The heterojunction solar cell had a structure of metal grid/ 500°A of a-Si:H/p-Si wafer/Ohmic contact. These cells gave an open circuit voltage (V_{oc}) = 0.51 (V) and short circuit current density (J_{sc}) = 5.5 mA/cm^2 under 50mW/cm^2 tungsten halogen lamp. Thin film transistors using nc-Si, with gate length/width (L/W) =450/65 gave field effect mobility of 18 cm^2/V-s, and Ion/Ioff of 1.25×10^5.

Introduction

ECR plasma deposition can control the properties of the plasma so that it can be applied to deposit nanocrystalline silicon (nc-Si) thin films or amorphous silicon (a-Si) for thin film transistors (TFT's) and solar cells [1]. With ECR deposition, ion bombardment and etching during growth can be controlled. Also, low pressures can minimize the radical-radical reactions. Other benefits of rf- generated plasma processing includes high fraction of ionization and dissociation, high electron kinetic temperature, and no need for an electrode inside the chamber which can reduce the contamination of samples [2].

In-situ mass spectroscopy [3] is used in the analysis of the plasma during the deposition. In the ECR process, we need to induce a good argon plasma and also reduce the defects from argon ions. Therefore, before beginning the deposition, it is helpful to check the RGA (residual gas analyzer) signals and try to obtain a good signal from the RGA. By using excess hydrogen, we can reduce dangling bonds that are present in the a-Si. This produces a-Si:H. It can improve the characteristics of the photo-conductivity and the properties needed for applications [4].

EXPERIMENT

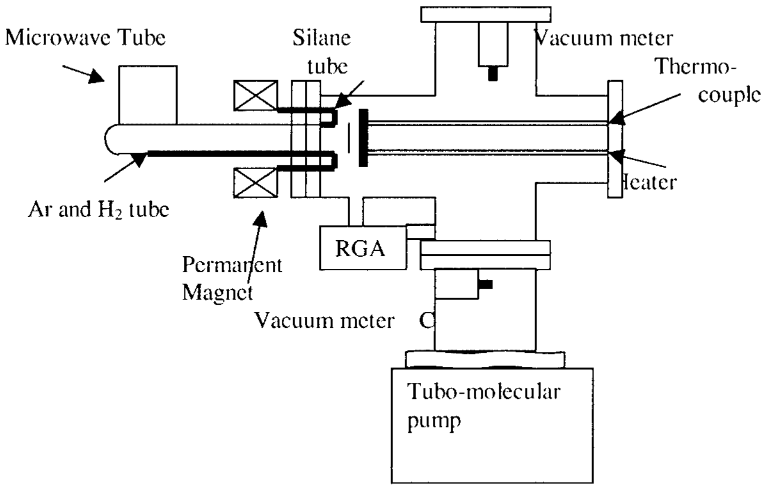

Fig 1. ECR chamber geometry.

The ECR-CVD geometry is shown in Fig.1 above. The filament of the RGA (SRS CIR200) in placed just below the plasma coming out of the quartz-tube near the substrate. Ar + H_2 and 2%SiH_4 in He are introduced through the gas feed tubes. 2%SiH_4 in He is decomposed due to the Ar plasma. Angle of the substrate is 90 degrees and the distance from the tube is ¾ inches. Two permanent magnets reside to control the plasma. The substrate holder is heated to 250 °C for a-Si and 400 °C for nc-Si. Microwave power is 600 Watts. Current-voltage (I-V) is measured to obtain the dark conductivity (σ_P) and photo-conductivity (σ_d) under an AM1.0 spectrum of 100cmW/cm^2 from a tungsten halogen lamp.

Data and Results

Before the ECR-CVD deposition, the proper conditions of deposition are confirmed using the RGA. Standard conditions were 5 mTorr of Ar and 52 mTorr to 64 mTorr of 2% SiH_4 in He.

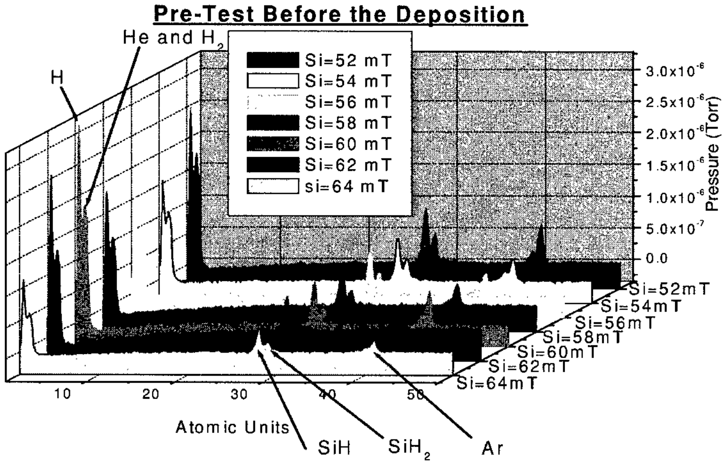

Fig. 2 RGA signal of the pre-test with changing amount of SiH_4

In Fig. 2, the RGA signals show the atomic units and the pressure of each gas. SiH_4 is decomposed into SiH, SiH_2, SiH_3, H and H_2. At 60 mTorr of SiH_4, the high peaks of H, SiH and SiH_2 are seen, indicating good decomposition. The result of the photo and dark conductivity ratio is below in Fig.3.

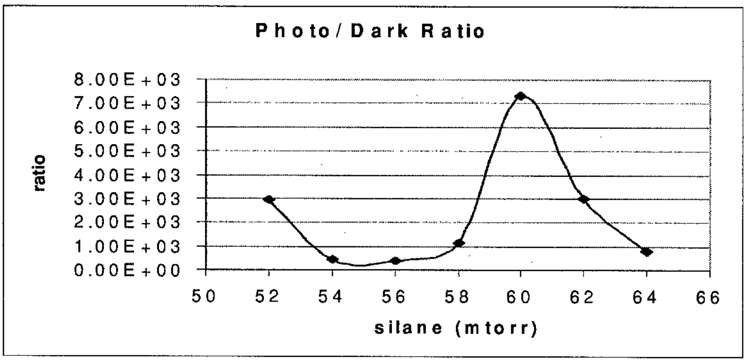

Fig. 3 The photo and dark conductivity ratio

The best conductivity ratio result was achieved at 60 mTorr of silane and 5 mTorr of Ar from Fig.3. The photo-conductivity is 1.58×10^{-5} S/cm, and the dark-conductivity is 2.16×10^{-9} S/cm at 60 mTorr of silane. In most of the cases, dark conductivities are similar, but improved photo-conductivity leads to the higher conductivity ratio of the samples.

Too much or too little silane is a disadvantage. In order to obtain better photo-conductivity, hydrogen was added during depositon. H_2 was changed from 0.5 mTorr to 3 mTorr. More than 4 mTorr of hydrogen did not give a good RGA signal. Amount of silane was changed from 52 mTorr to 68 mTorr. Since hydrogen can reduce the dangling bonds of SiH_x more effectively, the ratio of photo and dark conductivity was improved. The ratio results are in the Fig. 4.

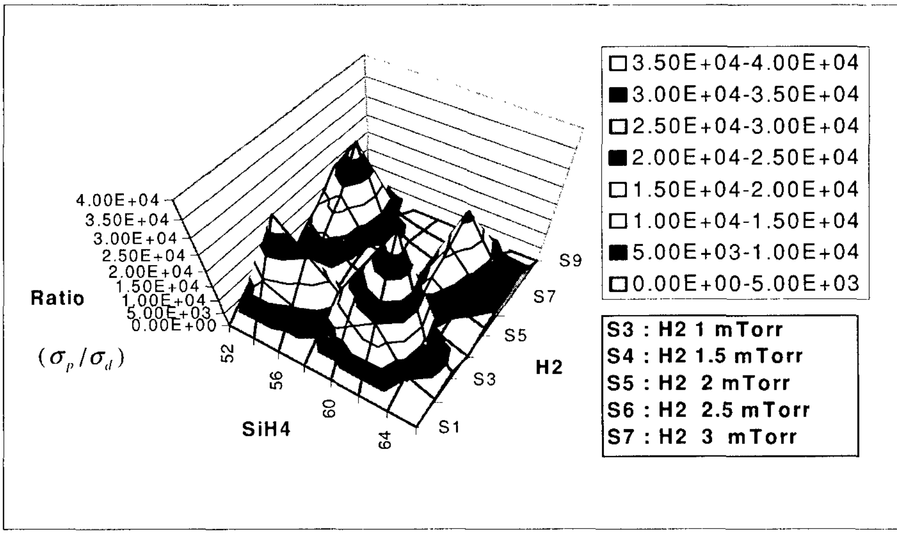

Fig. 4 The photo & dark conductivity ratio variation with SiH_4 and H_2

The best photo and dark conductivity ratio was 4.0 x 10^4 S/cm at 62 mTorr of silane, 1 mTorr of H_2, and 4 mTorr of Ar. The photo-conductivity was 1.12 x 10^{-4} S/cm, and the dark conductivity was 2.8 x 10^{-9} S/cm

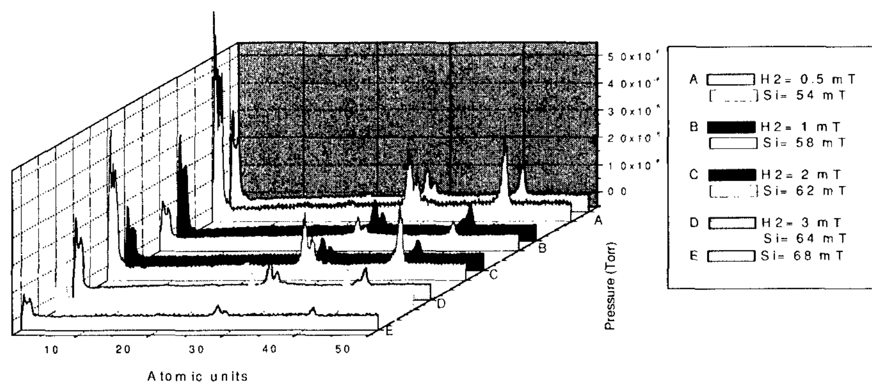

Fig. 5 Signal change with variation in H_2(filled box) or Silane (clear box)

The high peak H , H_2 and SiH_x are at 62 mTorr of silane. The RGA signals of the result is in Fig.5 . It proved the ratio related with gas decomposition. In this condition, TFT and solar cell sample current and voltage curves are in Fig. 6 and Fig.7.

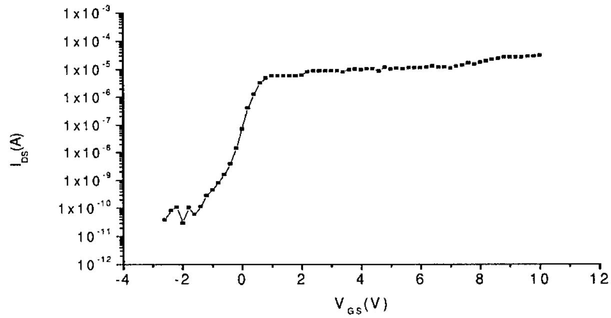

Fig. 6 TFT data for a transistor made form nc-Si

For the TFT of Fig.6, an inverted staggered structure was used with a gate oxide of thickness 100-200 nm deposited by PECVD. The gate length / width ratio is (W/L) = 450/85, and at the V_{DS} = 1 (V), field effect mobility was 18 cm^2/V-s. Turn-on and off current were $I_{on} = 2.5 \times 10^{-5}$ A and $I_{off} = 2.0 \times 10^{-10}$ A.

Solar cells with an area of $1 cm^2$ were fabricated with the back side having an Al Ohmic contact of 1000 A^o. a-Si was deposited with 250 °C substrate temperature for an a-Si solar cell and 400°C for a nc-Si solar cell with a thickness of 500 A^o . On the top, the grid line was 200-300 A^o Mg/ 800-1000 A^o Al. The current–voltage curve is below in Fig.7.

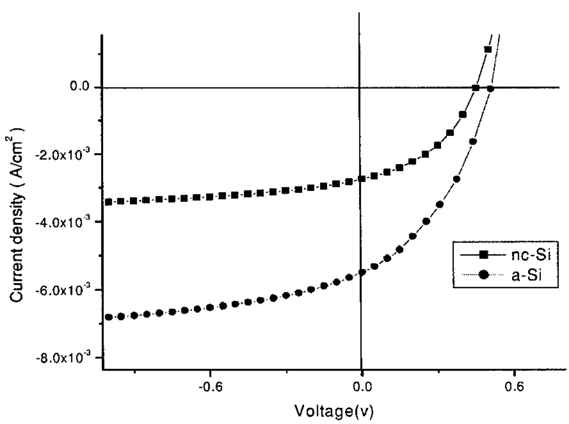

Fig. 7 nc-Si and u-Si solar cell J-V curve under 50 mW/cm^2 light.

The nc-Si solar cell has V_{oc}=0.45 (V) and current density ,J_{sc} = 2.8 mA/cm^2 under 50 mW/cm^2. The a-Si solar cell has V_{oc}= 0.51 (V) and J_{sc} = 5.5 mA/cm^2 under 50 mW/cm^2. The a-Si solar cell shows the better results.

Conclusion

The conditions of ECR-CVD deposition are very critical factors. Best conditions for a-Si:H deposition were 4 mTorr of Ar , 62 mTorr of SiH_4: He and 1 mTorr of H_2 with 250^{o}C substrate temperature.
The nc-Si was obtained using the same conditions of gases with substrate temperature of 400^{o}C. Proper combination of each gas is one of the important conditions in order to obtain a good ratio, however, pumping pressure and power are adjusted for inducing a good plasma.
The films were useful for producing solar cells and thin film transistors.

Acknowledgment

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